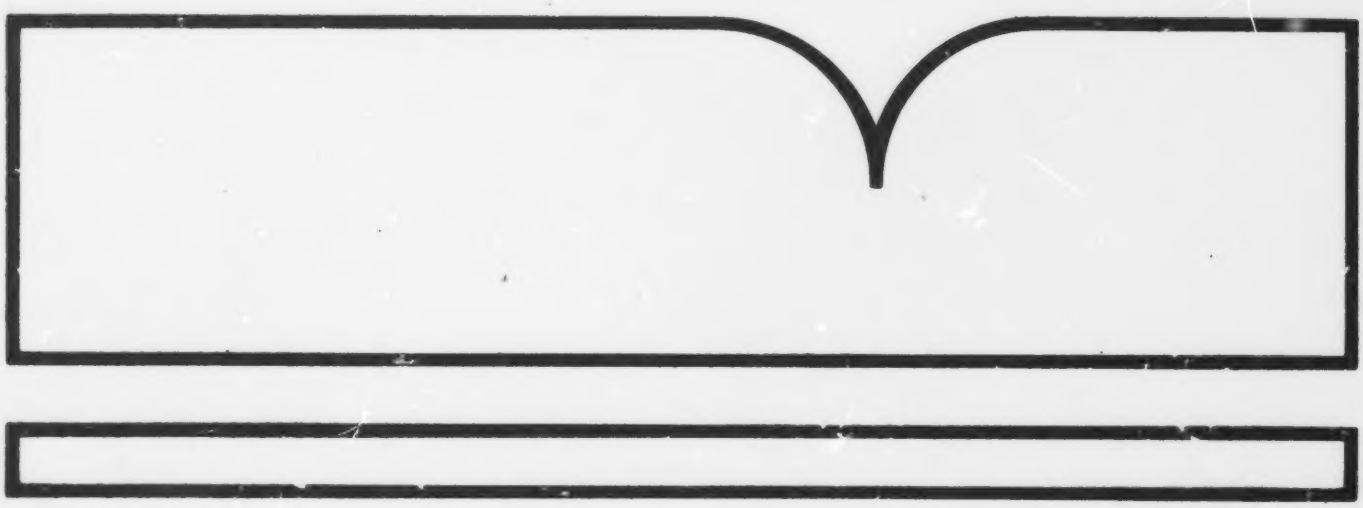
PB90-132929

Radon in Schools

(U.S.) Environmental Protection Agency, Research Triangle Park, NC

1989



U.S. Department of Commerce
National Technical Information Service
NTIS

AEERL-P-588

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/D-89/206	2.
3. RE PB90-132929	
4. TITLE AND SUBTITLE Radon in Schools	5. REPORT DATE
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Kelly W. Leovic	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS See Block 12	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. NA (Inhouse)
12. SPONSORING AGENCY NAME AND ADDRESS **EPA, Office of Research and Development** Air and Energy Engineering Research Laboratory **Research Triangle Park, NC 27711**	13. TYPE OF REPORT AND PERIOD COVERED Published paper; 5/88 - 9/89
	14. SPONSORING AGENCY CODE **EPA/600/13**

15. SUPPLEMENTARY NOTES AEERL project officer is Kelly W. Leovic, Mail Drop 54, 919/541-7717. Presented at Indoor Air Quality Conference, Clearwater Beach, FL, 10/19-20/89.

16. ABSTRACT

The paper discusses radon entry into schools, radon mitigation approaches for schools, and school characteristics (e.g., HVAC system design and operation) that influence radon entry and mitigation system design. It also discusses mitigation systems installed by the U.S. EPA in four schools. The primary source of radon entry into a school with significantly elevated radon levels is normally soil gas that is drawn in by pressure differentials between the soil surrounding the substructure and the building interior. If the building interior is at a lower pressure than the soil surrounding surrounding the substructure and radon is present in the soil, the radon can be pulled in through cracks and other openings that are in contact with the soil. The amount of radon in a given classroom depends on the level of radon in the underlying material, the ease with which the radon moves as a component of the soil gas through the soil, the magnitude and direction of the pressure differentials, the number and size of the radon entry routes, and dilution and mixing of the room air. HVAC systems in schools vary considerably and tend to have greater impact on pressure differentials--and consequently radon levels--than do heating and air-conditioning (HAC) systems in houses.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Soils Radon School Buildings Heating Ventilation Air Conditioning	Pollution Control Stationary Sources Soil Gas	13B 08G, 08M 07B 13M, 05I 13H, 13A

18. DISTRIBUTION STATEMENT **Release to Public**	19. SECURITY CLASS *(This Report)* **Unclassified**	21. NO. OF PAGES 24
	20. SECURITY CLASS *(This page)* **Unclassified**	22. PRICE

EPA Form 2220-1 (9-73)

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

EPA/600/D-89/206

Submitted for: Florida West Coast Chapter of ASHRAE Conference "A Positive Approach to Indoor Air Quality" (October 1989)

RADON IN SCHOOLS

Kelly W. Leovic
Air and Energy Engineering Research Laboratory
United States Environmental Protection Agency
Research Triangle Park, North Carolina 27711

ABSTRACT

The primary mode of radon entry into a school with significantly elevated radon levels is normally from soil gas that is drawn in by pressure differentials between the soil surrounding the substructure and the building interior. If the building interior is at a lower pressure than the soil surrounding the substructure and radon is present in the soil, the radon can be pulled in through cracks and openings that are in contact with the soil. The amount of radon in a given classroom will depend on the level of radon in the underlying material, the ease with which the radon moves as a component of the soil gas through the soil, the magnitude and direction of the pressure differentials, the number and size of the radon entry routes, and dilution and mixing of the room air.

Heating, ventilating, and air-conditioning (HVAC) systems in schools vary considerably and tend to have a greater impact on pressure differentials -- and consequently radon levels -- than do heating and air-conditioning systems in houses. If the HVAC system induces a negative pressure relative to the subslab area, radon can be pulled into the building. If the HVAC system pressurizes the building, it can prevent radon entry as long as the fan is running. However, school HVAC systems are normally set back or turned off on evenings and weekends and, even if the HVAC system pressurizes the school during operation, indoor radon levels may build up during setback periods.

This paper discusses radon entry into schools, radon mitigation approaches for schools, and school characteristics, such as HVAC system design and operation, that influence radon entry and mitigation system design. Mitigation systems installed by the U.S. Environmental Protection Agency (EPA) in four schools are also discussed.

NTIS is authorized to reproduce and sell this report. Permission for further reproduction must be obtained from the copyright owner.

INTRODUCTION

In late 1987, elevated levels of radon were identified in several rooms of a school in Fairfax County, Virginia. This led to extensive radon measurements in schools in Fairfax County in addition to other counties in Virginia, Maryland, Tennessee, and North Carolina. Over 40 schools in these states have been visited by EPA, and school characteristics that potentially influence radon entry and impact mitigation system design and performance were identified. Mitigation systems that had proven successful in house mitigation were then installed in several of these schools. Many of the systems were installed by school personnel with some assistance from EPA and an experienced radon diagnostician.

Although radon mitigation experience in schools is limited, this initial research indicates that radon reduction technologies proven successful in houses are applicable to some schools. The applicability of these mitigation approaches to other schools will depend on the unique characteristics of each school.

RADON ENTRY INTO SCHOOLS

The primary mode of radon entry into a school with significantly elevated radon levels is normally from soil gas that is drawn in by pressure differentials between the soil surrounding the substructure and the building interior. If the building interior is at a lower pressure than the soil surrounding the substructure and radon is present in the soil, the radon can be pulled in through cracks and openings that are in contact with the soil. The amount of radon in a given classroom will depend on the level of radon in the underlying material, the ease with which the radon moves as a component of the soil gas through the soil, the magnitude and direction of the pressure differentials, the number and size of the radon entry routes, and dilution and mixing of the room air.

Pressure differentials that contribute to radon entry can result from operation of a heating, ventilating, and air-conditioning (HVAC) system under conditions that cause negative pressures (in the building relative to the subslab area), indoor/outdoor temperature differences (including the "stack effect"), use of appliances or other mechanical devices that depressurize the building, and wind.

HVAC systems in schools and other large buildings vary considerably and tend to have a greater impact on radon levels than do heating and air-conditioning systems in houses. If the HVAC system induces a negative pressure in the building relative to the subslab area, radon can be pulled into the building through floor and wall cracks or other openings in contact with the soil. (Even if the HVAC system does not contribute to pressure differentials in the building, the natural stack effect

can cause the building to be under a negative pressure so that radon-containing soil gas is pulled into the school.) As seen in Figure 1, there is a trend between negative pressure (in the classroom relative to the corridor) and elevated levels of radon, with the highest radon levels in the rooms with the highest negative pressures.

If the HVAC system pressurizes the building -- which is common in many systems -- it can prevent radon entry as long as the fan is running. However, school HVAC systems are normally set back or turned off during evenings and weekends, and even if the HVAC system pressurizes the school during operation, indoor radon levels may build up during setback periods. Once the HVAC system is turned back on, it may take several hours for radon levels to be reduced. Adjustment of the setback timing may, in some cases, achieve acceptable indoor radon levels during periods of occupancy. Measurements with continuous radon monitoring equipment in each classroom with elevated radon levels are necessary to determine the appropriate setback timing in such situations.

Typical radon entry routes include cracks in the slabs, walls, and floor/wall joints, porous concrete block walls, open sump pits, and openings around utility penetrations. Radon present in crawl spaces may also enter a building. In addition, many schools have other radon entry points such as slab pour joints (control joints) and subslab utility tunnels.

Experience has shown that there can be large differences between radon levels in classrooms on the same floor. Causes for these room-to-room differences are thought to include variations in the soil under the classrooms, the construction between rooms, the number and size of cracks and openings in contact with the soil in different rooms, and the design and operation of the HVAC system. This room-to-room variability makes it difficult to detect and mitigate all the rooms with high radon levels unless every classroom on or below ground level is tested.

RADON MITIGATION TECHNIQUES

SUBSLAB DEPRESSURIZATION (SSD)

Subslab depressurization (SSD) has been the most successful and widely used radon reduction technique in slab-on-grade and basement houses, and, thus far, it has reduced radon levels in a number of schools. If HVAC system operation or the natural stack effect exerts a negative pressure in the building relative to the subslab area, then a successful SSD system must overcome this negative pressure.

Installation of an SSD system involves inserting pipes through the concrete slab to access the crushed rock or soil

beneath. A fan is then used to reverse the pressure differential; that is, cause the soil side of the slab to be at a lower pressure than inside the room. This reversed pressure relationship prevents radon-containing soil gas from entering the building.

The material under the foundation slab must be permeable enough to allow air movement under the slab so that adequate suction can be induced across the entire slab. (Subslab permeability or air flow is often referred to as subslab "communication" or "pressure field extension.") When subslab pressure field extension is inadequate, additional suction pipes may be able to increase the mitigated area.

Initial results indicate that SSD can reduce radon levels in some schools by over 90 percent if crushed aggregate or other permeable material is under the slab to allow for adequate pressure field extension. However, schools with poor subslab communication and those using return-air ductwork beneath the slab may require an alternative mitigation approach to SSD.

SEALING

The effectiveness of sealing alone as a radon reduction technique in schools is limited by the ability to identify, access, and effectively seal major radon entry routes. Most buildings have so many radon entry routes that sealing only the obvious ones may not result in a significant degree of radon reduction. Complete sealing of all radon entry routes is often impractical. In some buildings, certain areas will be difficult, if not impossible, to access and/or seal without significant expense. In addition, settling foundations and expanding floor cracks continue to open new entry routes and reopen old ones. Typical initial radon reduction from extensive sealing in houses is usually about 50 percent.

CLASSROOM PRESSURIZATION

A potential mitigation approach for schools is adjustment of the air-handling system to maintain a positive pressure in the school relative to the subslab area, discouraging the inflow of radon. This technique, referred to as pressurization, has been shown to be an effective temporary means of reducing radon levels in some schools, depending on the design of the HVAC system. If pressurization through the HVAC system is under consideration as a long-term radon mitigation solution in a given school, proper operation and maintenance of the system are critical. Responses to changes in environmental conditions and any additional maintenance costs and energy penalties associated with the changes in operation of the HVAC system must also be carefully considered.

IMPORTANT SCHOOL CHARACTERISTICS RELATIVE TO RADON ENTRY

To help understand the causes of elevated radon levels in schools and to better design school mitigation systems, three building components are of primary concern: the building substructure(s), the design and operation of the HVAC system(s), and the location of utility lines. This section discusses how these building components tend to affect radon entry in schools and how they may impact mitigation system design and operation.

SCHOOL SUBSTRUCTURES

The three basic substructure types are slab-on-grade, basement, and crawl space. The majority of substructures in the schools studied thus far are slab-on-grade. Schools often have one or more additions, and each addition may have a different type of substructure. Subslab aggregate (or gravel) is normally indicated on the construction plans; however, the grading of the aggregate -- and consequently the subslab communication -- is variable.

Because of larger building and room sizes, schools often have interior footings and/or grade beams that may create subslab communication barriers between areas. The location of subslab barriers and their influence on subslab communication will depend on building size and configuration, and on architectural preferences for carrying roof load. The locations of these barriers may affect the number and placement of SSD suction points in a slab-on-grade or basement structure, and foundation plans, if available, should always be examined when selecting suction point locations. This helps ensure that all areas with elevated radon levels are adequately treated by the SSD system.

HEATING, VENTILATING, AND AIR-CONDITIONING (HVAC) SYSTEMS

Understanding the school's HVAC system often plays an important role in determining the source of -- and the solution to -- the radon problem. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62-1981R "Ventilation for Acceptable Indoor Air Quality" should be consulted to determine if the installed HVAC system is designed and operated to achieve recommended minimum ventilation standards for indoor air quality. Sometimes schools and similar buildings were not designed with adequate ventilation, and in other instances, ventilation systems are not operated properly due to factors such as increased energy costs or uncomfortable conditions caused by a design or maintenance problem.

HVAC systems in the school districts initially researched by EPA include: central air-handling systems, room-sized unit ventilators, and radiant heat. Unit ventilators and radiant heat were found both with and without a separate ventilation system. Central air-handling systems and unit ventilators tend to be most

prevalent in newer schools, particularly if air-conditioned. Often, because of additions, schools may have more than one type of HVAC system. The types of HVAC systems are discussed below in terms of radon entry and mitigation approaches.

Central-Air Handling Systems

Central air-handling systems can vary widely in size and configuration, and the different types of systems will tend to have unique effects on radon entry and subsequent mitigation. Three types of central air-handling systems common in schools are summarized below: single-fan systems, dual-fan systems, and exhaust-only systems.

In single-fan systems the air is distributed to the rooms (normally under pressure) by the air-handling fan, and the return air is brought back by the same fan. These systems are similar to forced-air systems in houses, except that fresh air can usually be mixed with the return air. The air-handling fans may operate continuously during the day, or they may operate only when heated or cooled air is required, cycling on and off throughout the day with thermostat control. In any case, the systems are normally set back or turned off during evenings and weekends. These single-fan systems are normally designed to generate neutral or positive pressures in all rooms. In a single-fan system, stale air leaves the building either through a separate exhaust system, by relief, or by exfiltration through cracks and openings due to overpressurization by the fan (if fresh air is brought into the system).

Larger air-handling systems often employ a dual-fan system: an air-distribution fan and a smaller return-air fan. The return-air fan allows for forced exhaust of return air. Louvers regulate the amount of fresh air brought into the air supply and the amount of return air that is exhausted. Dual-fan systems are usually designed so that they generate positive pressures in all rooms when operating; however, if the return-air fan pulls more air from a room than the supply fan is furnishing, the room can be run under negative pressure causing soil gas to enter the room through openings to the soil beneath the slab. The fans usually operate continuously during the day and are either set back or turned off during evenings and weekends.

Although single- and dual-fan systems are commonly designed to operate at positive or neutral pressures, pressure measurements in schools have indicated that such systems can cause significant negative pressures in the building. HVAC system modifications (such as reducing the amount of fresh-air intake), lack of maintenance (such as dirty filters), unrepaired damage, or other factors can result in substantial negative pressures in some rooms, thus increasing soil gas entry.

If positive pressures are not being achieved in a single-fan system, the system should be checked to ensure that the fresh-air intake meets design specifications and that the intake has not

been closed or restricted. Increasing the fresh-air intake and operating the fan for a sufficient time prior to occupancy and continuously while the school is occupied will help to reduce radon levels that have built up during setback periods and will maintain low radon levels during occupied hours by preventing radon entry by maintaining a positive pressure and providing fresh (dilution) air. In dual-fan systems, the return-air fan can be set back or restricted so that all of the rooms are under a positive pressure with only the supply fan operating. The fresh-air intake to the supply fan can also be increased up to the design limit of the system. If radon control through HVAC system operation is under consideration as a permanent mitigation strategy, proper system operation and maintenance are critical. Many schools have installed SSD systems in order to control radon levels even when the HVAC system is not operating.

The third type of central air-handling system is an exhaust-only system in which no supply air is provided mechanically. Such systems are generally used for ventilation in schools that heat with radiant systems or unit ventilators and have no central air-handlers. The fans exhaust air through a central ceiling plenum above the rooms or with roof mounted exhausts in many locations. These systems are designed to draw fresh air into the rooms by infiltration through above grade cracks and openings; however, radon can enter through below grade cracks and openings. The fans in exhaust-only systems are normally off at night but may operate continuously during the day. This can generate a negative pressure in all rooms and, consequently, increase the potential for radon entry. For schools with exhaust-only ventilation systems, positive pressurization will probably require major modifications if the HVAC is considered as part of the mitigation strategy.

Unit Ventilators

These self-contained units provide heating and/or air-conditioning in individual rooms. They are usually installed on outside walls with an enclosure which contains finned radiators and/or coils. They can also be located overhead in each room and are sometimes above the drop ceiling. Unit ventilators normally contain one or more fans and a vent to the outdoors so that fresh air can be pulled in by the fan(s). An adjustable damper allows a variation in the mix of recycled room air and fresh air fed to the circulating fan. Fresh-air intake can be minimal because of obstruction of the outdoor vents due to poor maintenance or energy conservation practices. (Units that do not provide any outdoor air by design are referred to as fan coil units, not unit ventilators.)

In some cases there is a central-building exhaust-fan system in schools with unit ventilators, as discussed above. This exhaust fan is intended to provide ventilation by pulling air in though the unit ventilators (if their fresh-air vents are open), but it also creates a significant negative pressure in the rooms. This negative pressure can pull radon into the rooms with the

soil gas. If fresh-air intakes in the unit ventilators are blocked for any reason, operation of exhaust-only fans will increase the negative pressure in the building relative to the subslab area.

Radon mitigation strategies in schools with unit ventilators might include (1) opening the fresh-air vents to improve ventilation and running the unit ventilator fans continuously to pressurize the room, (2) replacing an exhaust-only ventilation system with a system that operates under a slight positive pressure, or 3) installation of a SSD system that could overpower all negative pressures in the building. If the current HVAC system is providing adequate ventilation to the building or if options (1) and (2) are not feasible, option (3), SSD, would be the most practical strategy if there is good subslab communication.

Radiant Heat Systems

Radiant heat systems in schools tend to be of three types: hot water radiators, baseboard heaters, or warm water radiant heat within the slab. Schools heated with radiant systems should have a ventilation system to achieve the fresh air requirements recommended by ASHRAE; however, many of these schools provide no ventilation other than infiltration. In other schools, there are exhaust ventilators on the roof. These can be passive, allowing some ventilation through the stack effect, or they can be powered. Powered Roof Ventilators (PRVs) can cause significant building depressurization, particularly if a fresh air supply is not provided. This can cause considerable radon entry into the building while such exhaust systems are operating.

If SSD is under consideration as a mitigation option in a school with intra-slab radiant heat, the building plans should be carefully studied to avoid damaging any piping when placing the SSD points. An infrared scanning device can be used to help locate the exact position of subslab pipes. Satisfactory locations for SSD pipes may be very limited in such schools.

LOCATION OF UTILITY LINES

The location of entry points for utility lines can have a significant influence on radon entry in schools since they can provide an entry route from the soil into the indoor air. Utility line locations depend on many factors such as substructure type, HVAC system, and architectural needs or practices. Utility lines located above grade should not cause significant radon entry problems.

In slab-on-grade and crawl space schools, the utility penetrations from the subslab or crawl space area to individual rooms are frequently not completely sealed, leaving openings between the soil and the building interior. For example, there is a potential for radon entry around plumbing penetrations and

electrical conduits.

In some slab-on-grade schools, the utility lines are located in a subslab utility tunnel that tends to follow the building perimeter or central corridor. Utility tunnels often have many openings to the soil beneath the slab-on-grade and, consequently, can be a potential radon entry route. In addition, risers to the unit ventilators frequently pass through unsealed penetrations in the floor so that soil gas in the utility tunnel can readily enter the rooms. If the surrounding soil has elevated radon levels, a utility tunnel could be a major radon entry route in schools. If no asbestos is present, it is possible that the utility tunnel could be used as a radon collection chamber for a SSD system.

MITIGATION CASE STUDIES

Following the qualitative assessment of school characteristics relevant to radon entry, mitigation systems were installed in several schools. Case studies of four of the Maryland installations follow.

DATA COLLECTION METHODOLOGY

To assist in understanding radon entry into the schools and to design effective mitigation systems for the schools, continuous data were collected as part of the diagnostic measurements. A portable data monitoring system recorded Julian Day, hour, differential pressure (three sensors), and temperature (four sensors). Radon data were collected with a Pylon AB-5, a continuous radon monitor (CRM). There was no interface between the CRM and the data logger, and software was developed so that the CRM and data logger data could be merged in a computer for further analysis. Hourly data averages were computed from sensor readings collected approximately every 5 seconds. This system allows for approximately 2 weeks of unattended data storage. Not all of the sensors were used during each experiment, and the positioning of sensors varied according to building size and configuration.

In addition to continuous data, 5-minute radon grab samples were occasionally collected with the CRM during visits to the schools. Spot pressure differential measurements with a micromanometer were also made in a few cases when setup of the data logger was not possible. To determine the coverage of subslab depressurization systems, pressure field extension measurements were sometimes made. Holes, 0.25 in. (1 in. = 2.54 cm) in diameter, were drilled at various distances and in various directions from the suction holes, depending on building size and configuration, and the resulting test hole pressure measured with a micromanometer. Radon grab samples were occasionally collected through these test holes.

CASE STUDY A: PRINCE GEORGES COUNTY, MD

Radon levels in this school were initially measured in February 1988 with charcoal canisters: one classroom tested above 40 pCi/L, a teachers' lounge tested above 20 pCi/L, and several other classrooms tested between 4 and 20 pCi/L. The building is slab-on-grade construction with a large two-fan air handling system. The HVAC system had a rated capacity of 51,000 cfm (1 cfm = 0.47 L/s) of air supply and 34,000 cfm of return air. Louvers regulate the amount of fresh air and recycled air in the system. This would result in positive pressure in all rooms if the system were properly balanced. However, continuous radon and pressure measurements indicated that many of the rooms were under negative pressure relative to the subslab area when both the supply and return fans were in operation.

The room with the highest radon level (usually 10 to 20 pCi/L) typically measured between 0.06 and 0.08 in. WC negative pressure relative to the subslab. When the return air fan was turned off, the pressure in the room became positive, and radon levels decreased to less than 2 pCi/L. Examination of the air-handling system showed that the air supply fan had been damaged, resulting in a significant capacity loss. As a result, the supply fan was actually supplying less air than the return air fan was removing, causing a negative pressure in many rooms.

This same room with the highest radon level and the highest negative pressure also had a very large floor-to-wall crack along one wall. This particular crack was an expansion joint where two parts of the building were joined. The material in the expansion joint had disintegrated, and the parts appeared to have separated, leaving a 1-In. gap between the floor and wall. This gap was concealed by an aluminum angle iron installed when the building was built. When the return fan was operating, initial tests in this room showed a large flow of radon-containing soil gas out of this crack. The radon level was about 500 pCi/L in the soil gas entering the room through the crack, the same measured under the slab in the middle of the room. When the return air fan was turned off and the room was pressurized by the air supply fan, room air flowed into the crack and consequently no soil gas entered. The pressure in the room relative to the subslab increased to about 0.01 in., and radon levels in the room quickly dropped below 2 pCi/L. The floor-to-wall crack was sealed with backer rod and urethane caulking. This sealing decreased radon levels only slightly when both fans were off, indicating other soil gas entry points in the room.

The influence of HVAC operation on the pressure differential between this room and the subslab area and the resulting radon levels in the room are displayed in Figure 2 for a 7-day period. (The return air louvers were closed during these measurements.) While the HVAC system is operating, the room is at a higher pressure than the subslab area and, consequently, radon entry is reduced. However, when the HVAC system is turned off during night and weekend setback, pressure in the room becomes negative

relative to the subslab area and radon levels increase.

As a temporary solution to reduce radon levels, the return air fan was left off and the HVAC system operated with only the air supply fan. Under these conditions, all rooms showed positive pressure and had radon levels below 2 pCi/L during HVAC operation. The damaged supply fan has now been replaced and the air supply and air return systems are being balanced.

As a precaution to reduce radon entry when the air handlers are not operating during night or weekend setback, two fan-assisted subslab depressurization points have been installed. It is anticipated that this will be an effective mitigation system since the school was constructed on 4 in. of subslab aggregate. Follow-up testing was initiated during the 1988-89 heating season.

CASE STUDY B: WASHINGTON COUNTY, MD

This is a small school built on the side of a hill with a walkout basement along the lower side. The unexcavated area is slab-on-grade with the slab extending over the basement area and resting on steel bar joists. The foundation walls are concrete block. The interior wall of the basement supports the end of the bar joists and the slab. This wall is not painted or waterproofed on either side. Building plans specify 4 in. of subslab aggregate.

The HVAC system consists of a single-fan system on each floor. A fresh air intake into the return air duct is under negative pressure during fan operation. Pressure measurements indicate that the building is under positive pressure even when the fresh air intake is set for minimum supply. However, since the HVAC system is normally set to run only when heating or cooling is required, the system may not operate during mild weather. In addition, the temperature in the below-grade part of the school is often buffered and, consequently, the basement HVAC system does not run as often as the upstairs system.

Radon levels in all rooms were measured with charcoal canisters over a weekend in May 1988 with air handlers off. Measurements ranged from 78 to 82 pCi/L in the basement and from 18 to 33 pCi/L on the first floor. Subslab and block wall grab samples measured as high as 1500 pCi/L.

Continuous radon measurements were made on both floors of the school during all phases of mitigation. Before mitigation, radon levels rose dramatically at night if the air handlers were off but did not rise during continuous operation. Pressure measurements indicated that operation of the air handlers produced a slight positive pressure in the building relative to the subslab area, thus reducing soil gas entry. In the hottest part of the summer, radon levels rose dramatically overnight when the air handlers were off. It is suspected that a night stack

effect resulted since the hot inside daytime temperatures did not decrease as rapidly at night as the outdoor temperature. Overnight levels as high as 150 pCi/L were reached in the basement, and levels as high as 100 pCi/L were reached on the first floor when the air-handling fans were off during hot weather. Continuous operation of the HVAC reduced radon levels to less than 4 pCi/L within an hour.

As a temporary solution, the HVAC system was run continuously while the school was occupied. For a permanent solution, subslab depressurization points were installed in phases in both the basement and on the first floor. Due to the high radon levels and complex foundation, it was anticipated that several suction points would be needed.

A 1 ft (1 ft = 0.305 m)-diameter subslab suction pit was installed in the basement with a 4-in.-diameter pipe, and radon reduction was about 50 percent with the subslab pressure field extending less than 30 ft. The suction pit was excavated to a diameter of about 3 ft with an additional decrease in radon levels and an increase in pressure field extension. The suction fan was replaced with a larger fan, resulting in additional reductions in radon levels. This also increased pressure field extension to 40 ft. This basement suction point also caused some measurable depressurization under the first floor slab, indicating some communication between the slabs.

To evaluate the effectiveness of the single-point subslab suction system in this school and to investigate the effects of the single-fan HVAC system on mitigation performance, Figure 3 shows radon and pressure measurements in the school over a 10-day period. The first-floor single-fan HVAC system was operated continuously during the school week to reduce radon levels while the school was in session on the first floor. Since the basement was unoccupied during the monitoring period, the basement HVAC system was not operated. Over the weekend (day 156), the HVAC system and the single-point subslab suction system on the first floor were turned off, and the radon levels rose quickly to more than 70 pCi/L on the first floor and 140 pCi/L in the basement. On day 157 the subslab suction system remained off, but the first-floor HVAC system was turned on. Radon levels on both floors dropped, and the differential pressure under the slab and within the block wall became slightly negative relative to the room. On days 158-163, both the HVAC system and subslab suction system were operating, and radon levels remained low. On days 164 and 165, the subslab suction system was operated and the first-floor HVAC system was off. This resulted in an increase of first-floor radon levels to 40 pCi/L, indicating that one suction point was not adequate if the HVAC system was not operating.

To ensure acceptable radon levels on the first floor while the HVAC system was not in operation, another suction point with a 3-ft-diameter suction pit was installed on the first floor. Addition of this suction point reduced levels on the first floor although radon levels on both floors still rose above 10 pCi/L at

night with the HVAC system off.

Pressure field extension measurements made with these two suction points operating indicated incomplete coverage of both floors. Consequently, two additional suction points with 1-ft-diameter suction pits were installed in the basement, and a fifth suction point with a 1-ft-diameter suction pit was installed on the first floor.

Nine pressure field extension measurements showed overlapping fields between suction points in the basement area, indicating that all of the basement subslab was adequately depressurized. Basement radon levels measured less than 2 pCi/L with the air handlers off and the mitigation systems operating; however, first-floor radon levels still rose above 4 pCi/L at night with the air handlers off.

Based on mapping of subslab radon levels in more than 20 test holes on the first floor, three additional suction points were installed, each with a 6-in.-diameter pipe and a 1-ft-diameter subslab suction pit. Two points were manifolded to a single fan, and a separate fan was installed on the other suction point. After installation of these last three suction points, radon levels stayed below 4 pCi/L on both floors, except for occasional brief excursions at night. A larger fan was installed, and this appears to be reducing radon levels satisfactorily. More than 10 pressure field extension measurements made on the first floor showed little variation in the short-term when the first-floor HVAC system was turned off. This indicates that the present system is achieving adequate coverage even when the HVAC fan is not operating.

Although subslab suction was effective in solving a serious radon problem at this school, it was surprising that it took eight suction points. Aggregate under the slab was confirmed visually at every suction point; however, the aggregate used was probably unscreened "crusher run," containing a great deal of fines. This tends to confirm the belief that screened, coarse aggregate (0.75 to 1.25 in.), essentially free of any material less than 0.25 in. diameter, is preferred for optimal operation of subslab depressurization systems.

CASE STUDY C: WASHINGTON COUNTY, MD

This school building is slab-on-grade with block walls and no utilities below grade except sanitary sewers. The original building was constructed in 1956 and has four area air handlers for heating and ventilating with a central boiler room. A classroom wing was added in 1968 and unit ventilators are in each room. None of the building is air-conditioned. Construction plans specified 4 in. of subslab aggregate under the entire building. Elevated radon levels were found in the locker rooms on each side of the gymnasium in the original building and in the new classroom wing. Mitigation of each of these areas is

discussed separately.

Original Building--Locker Room Mitigation

Although the locker rooms and gymnasium are on the same air handler, the gymnasium measured 2 pCi/L; the girls' locker room, 5 to 6 pCi/L; and the boys' locker room, 5 to 19 pCi/L. Further examination indicated that each locker room area had large exhaust fans to remove odors and shower steam. Differential pressure measurements (using a micromanometer) with the air handler and exhaust fans operating correlated with the radon levels showing that the gymnasium was slightly positive, the girls' locker room area slightly negative, and the boys' locker room area significantly negative.

Construction plans showed that each locker room area was a continuous slab over aggregate. As a result, a subslab suction point, using a 6-in. pipe, was placed in each locker room area with a 1-ft-diameter suction pit. Both locker room areas measured less than 4 pCi/L with the exhaust fans and the subslab depressurization systems operating, indicating that the subslab suction systems effectively overcame the negative pressures caused by the exhaust fans.

New Classroom Wing

Weekend charcoal canister measurements were made in April 1988 in this wing with the unit ventilators off. All but one room measured above 4 pCi/L: a room in the northeast corner measured 27 pCi/L. Levels decreased from north to south in this wing, as did subslab radon levels. A CRM was placed in the room with the highest radon levels. When the unit ventilator was off, levels above 20 pCi/L were reached nightly but remained below 2 pCi/L when the unit ventilator was run continuously. Pressure measurements with a micromanometer confirmed that the unit ventilator was pressurizing the room slightly.

Since the unit ventilators are off at night (except in extremely cold weather when they are cycled), it was decided to install two subslab depressurization points in the wing. These 4-in. suction pipes were installed in the hall and manifolded with an above-ceiling 6-in. pipe running to a fan at the north end of the building. One suction point was installed with a 3-ft-diameter suction pit about 20 ft from the east end of the hall, and the other suction point was installed with a 1-ft-diameter suction pit about 40 ft west of the first point. Pressure field extension measurements indicated that the two fields overlapped, and all of the wing was depressurized to the outside walls except for the southernmost classrooms.

Since the pressure field extension around the 1-ft-diameter suction pit was not as great as around the 3-ft-diameter suction pit, the 1-ft-diameter suction pit was increased to 3 ft in diameter. This extended the measurable depressurization area by 10 ft to the south (enough to reach the last two classrooms) and

about doubled the amount of depressurization in the test holes in all directions around the suction point. With the subslab depressurization system operating and the unit ventilator fans off, radon levels were less than 4 pCi/L in all classrooms.

CASE STUDY D: WASHINGTON COUNTY, MD

The original building of this school was built in 1958 and is heated with hot water radiant heat in the slab. In 1978 a kindergarten room was added to the original building, and a separate building (referred to as Building B) was built, containing four classrooms, a library, a teachers' workroom, a conference room, and restrooms. The kindergarten room is heated with hot water radiant heat, and the new building is heated with unit ventilators. Office space in the original building is air-conditioned with a window unit. No other area of either building is air-conditioned.

The original building has two 3600-cfm roof-mounted fans that could be used to exhaust air in plenums over the hall ceiling. Each room has a ceiling vent connecting to these hall plenums. However, the exhaust fans are never used. Consequently, the building has no active ventilation system. Plans showed that the original building had 6 in. of aggregate under a 6-in.-thick slab (containing hot water pipes) and Building B had 4 in. of aggregate under a 4-in. slab.

All rooms in both buildings were tested with charcoal canisters over a weekend in mid-April 1988. The eight rooms in Building B measured between 17 and 20 pCi/L. It is believed that the unit ventilators were off during the testing weekend, but this could not be confirmed. Seven tests in the classrooms, library, and multi-purpose room in the original building measured between 12 and 23 pCi/L. Mitigation of the two buildings is discussed separately.

Building B (Unit Ventilators)

A CRM was placed in one of the classrooms in Building B to measure the effects of unit ventilator operation on radon entry. It was found that radon levels would rise overnight to more than 20 pCi/L with the ventilator off but would remain below 2 pCi/L with the ventilators on. Again, this shows that this type of ventilator can pressurize the room slightly, preventing radon entry when run continuously.

Since the ventilators are off during night setback, a four-point subslab depressurization system was installed. Four 4-in.-diameter pipes were connected to two 6-in. manifold pipes above the drop ceiling with a common suction fan. (Two vertical pipes are manifolded to each overhead pipe.) Pressure field extension measurements indicated that depressurization extended 50 ft, the minimum distance necessary to reach all parts of the slab.

With the subslab system operating and the unit ventilators off, all rooms remained below 4 pCi/L. However, based on the pressure field extension measurements, the system may be marginal during cold weather. If radon levels rise above 4 pCi/L, it is believed that subslab depressurization can be improved by sealing the floor-to-wall opening. Expansion joints (0.25 in. in width) around all of the slabs in the building are deteriorating, leaving significant openings to the subslab. This probably leads to some short circuiting of the subslab depressurization system.

Original Building (Intra-Slab Radiant Heat)

Subslab suction on this intra-slab radiant-heated building was a challenge since construction plans showed that the hot water pipes in the slab were 15-in. or less apart over the entire building. As a result, it was difficult to locate an area where a 6 in. subslab suction point could be placed without damaging a hot water pipe. A 3-ft-square area without water pipes was finally located in each room. A hole was successfully cut through one of these areas. The plans indicated that the aggregate was a minimum of 6 in. deep, much deeper than at any other school examined. A 6-in.-diameter suction pipe was installed with a 3-ft-diameter pit. Pressure field extension was far greater than expected, and depressurization could be measured as far as 90 ft from the suction hole. These results were surprising since the aggregate appeared to be some type of "crusher run" aggregate with a certain amount of fines. However, in leveling the aggregate before pouring the concrete, it is probable that most of the fines sifted to the lower portion of the aggregate bed, leaving a fairly thick area of large-diameter aggregate immediately under the concrete. It is believed that this layer of coarse stone made for a much greater pressure field extension and will be studied further. Preliminary follow-up tests indicate that this one suction point will solve the radon problem in the original building.

To analyze the effectiveness of a single-point subslab suction system and to investigate the pressures that control radon levels in schools during hot weather, radon, pressure, and temperature were monitored continuously in one classroom, as shown in Figure 4. The classrooms were kept closed during this period of very hot weather, and there is no ventilation system in this building. When the subslab suction system was turned off from day 222 through day 225, the radon levels quickly rose and followed a diurnal cycle that seems to match the temperature cycle. When the outdoor temperature was coolest relative to indoor temperature, the radon levels were highest. This can be expected from the stack effect, as discussed in Case Study B. Although a small positive pressure was measured across the slab during this period, it does not show significant diurnal variation. The differential pressure across an outside classroom wall does not show much correlation with the radon levels, except for a sharp dip in the middle of day 224 that may be due to wind.

Kindergarten Room

Since the kindergarten room is an addition, the subslab area does not communicate with the original building. Consequently, a suction point was put in a closet adjacent to a restroom where the hot water pipes were spaced 24 in. apart to clear the sewer line of the commode. This suction point lowered radon levels to less than 2 pCi/L. No pressure field extension measurements were made for fear of damaging a heating water pipe.

PRELIMINARY FINDINGS ON SCHOOL MITIGATION

The following preliminary conclusions can be drawn from the EPA's experience in assisting in the installation of radon mitigation systems in Maryland, Virginia, Tennessee, and North Carolina schools. These conclusions are based on limited studies and will be verified and expanded with further research.

1. One of the most significant factors contributing to elevated levels of radon in schools and influencing the mitigation approach is the design and operation of the HVAC system. The complexities of large building HVAC systems present problems not previously encountered in house mitigation.

2. Pressure control through continuous HVAC fan operation can often be an effective temporary solution to reduce elevated radon levels in schools, depending on HVAC system design. Whether such a technique is a feasible long-term solution depends on factors such as the proper operation of the system by maintenance personnel, variations in outside environmental conditions, and any additional maintenance costs and energy penalties associated with increased operation of the HVAC system.

3. A subslab depressurization system can usually overcome negative pressures induced by HVAC operation in schools if there are no return air ducts under the slabs. As with houses, subslab depressurization is more successful (and requires fewer suction points) when the slab is poured over clean, coarse aggregate.

4. Effective mitigation of schools using subslab depressurization requires greater fan capacities and suction pipe diameters than does mitigation of houses. The capacities of the fans used in these school installations were typically at least 300 cfm (at 0.75 in. WC) compared to capacities of about 150 cfm (at 0.75 in. WC) for fans commonly installed in house subslab depressurization systems. Suction pipe diameters of 4 to 6 in. often proved successful in these installations, compared to pipe diameters of 4 in. or less typically used in houses.

ACKNOWLEDGMENTS

We would like to thank all the school personnel who contributed to the information presented in this paper.

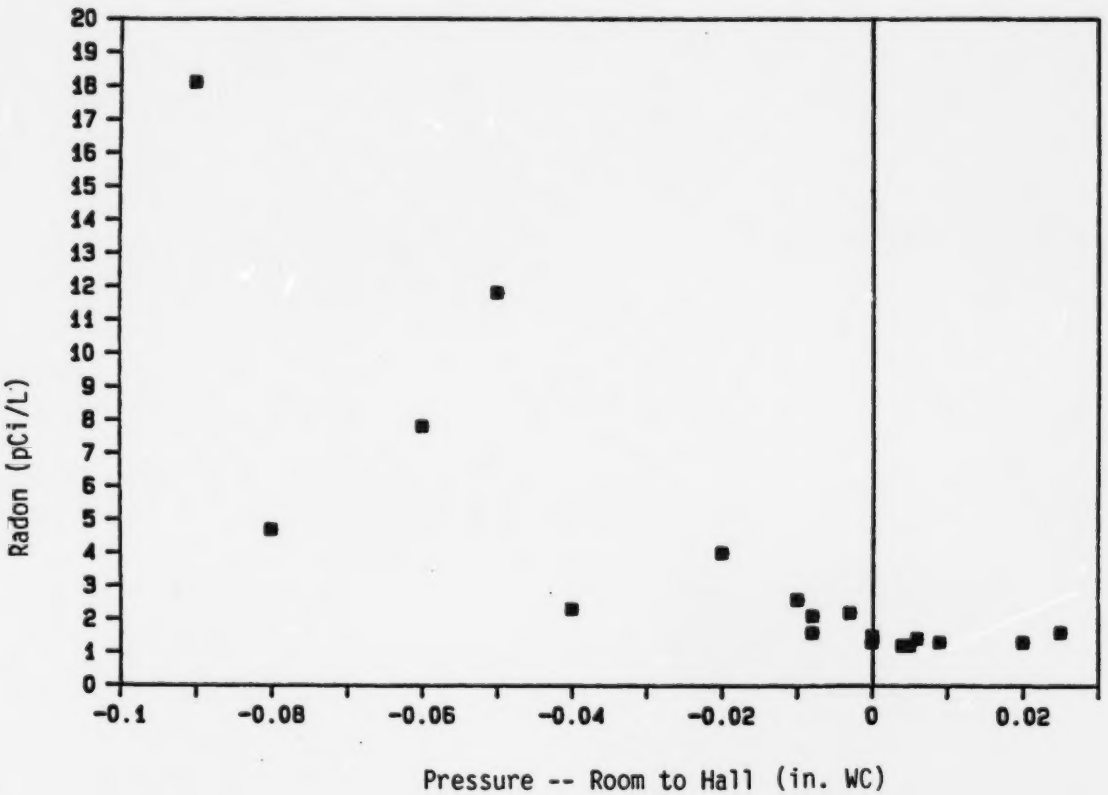


Figure 1. Correlation Between Room Pressure--Relative to Hall--and Radon Level

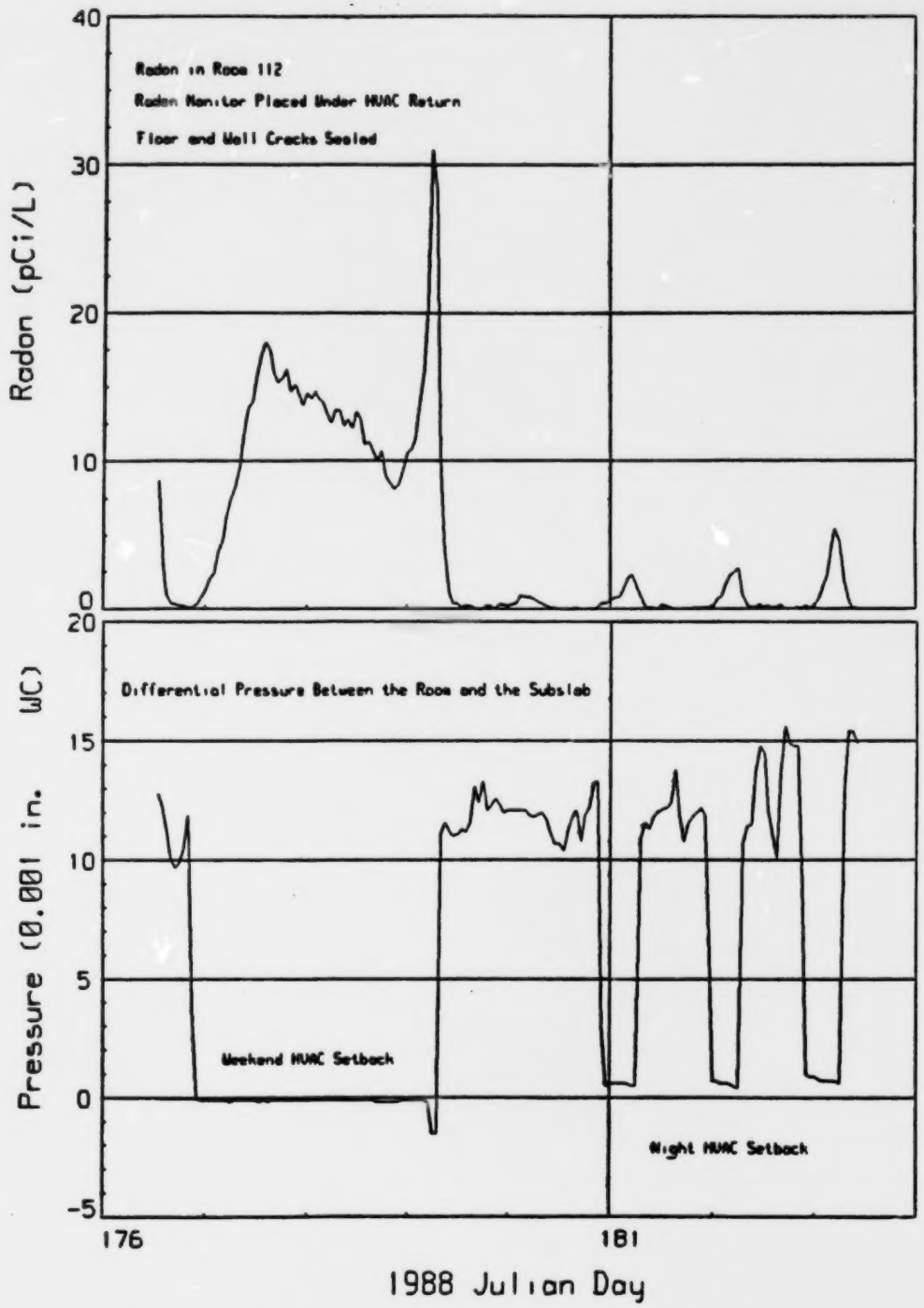


Figure 2. Influence of HVAC Operation on Radon Levels (Case Study A).

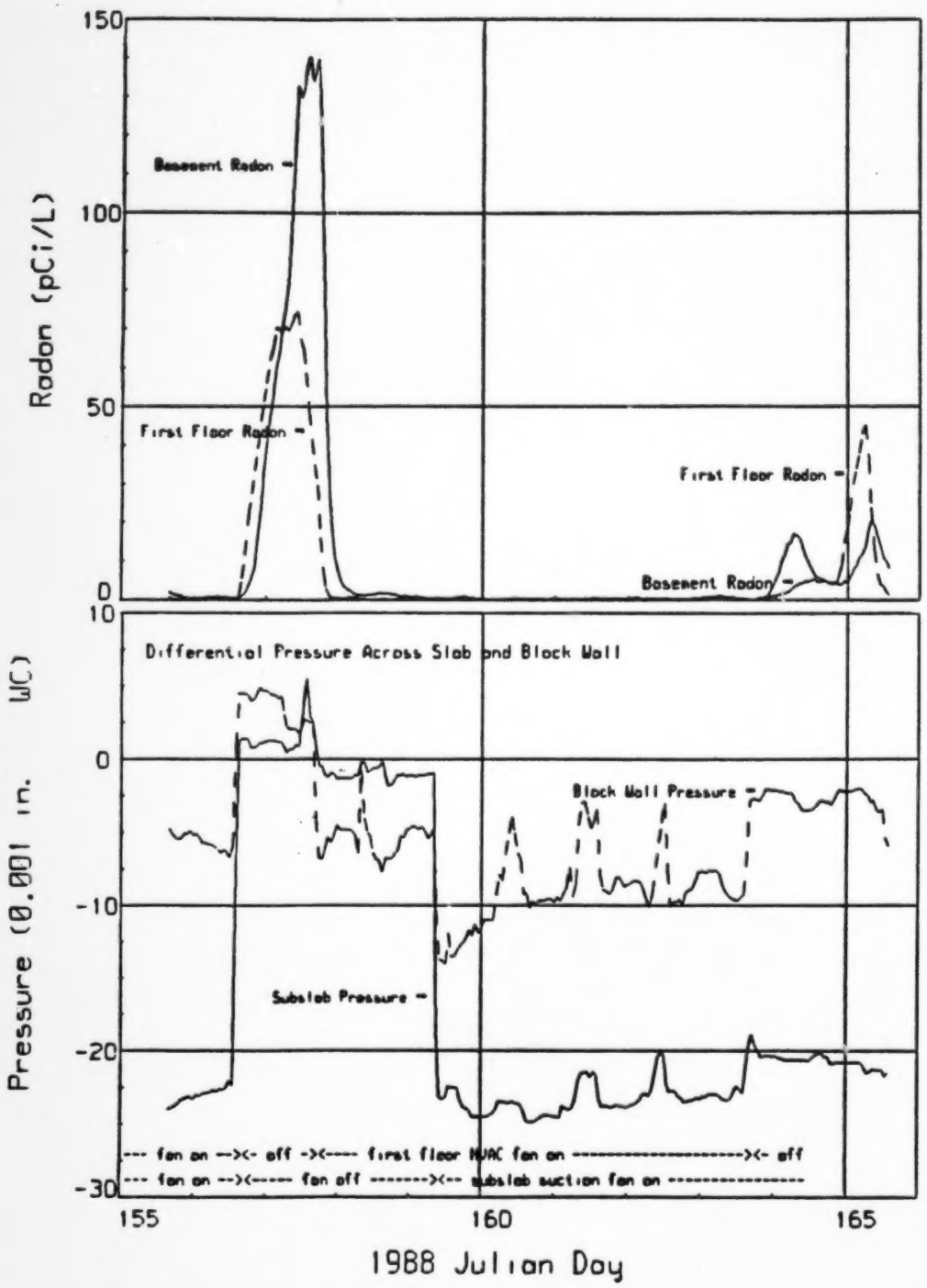


Figure 3. Influence of HVAC Operation and Single Point Subslab Depressurization on Radon Levels and Pressure (Case Study B).

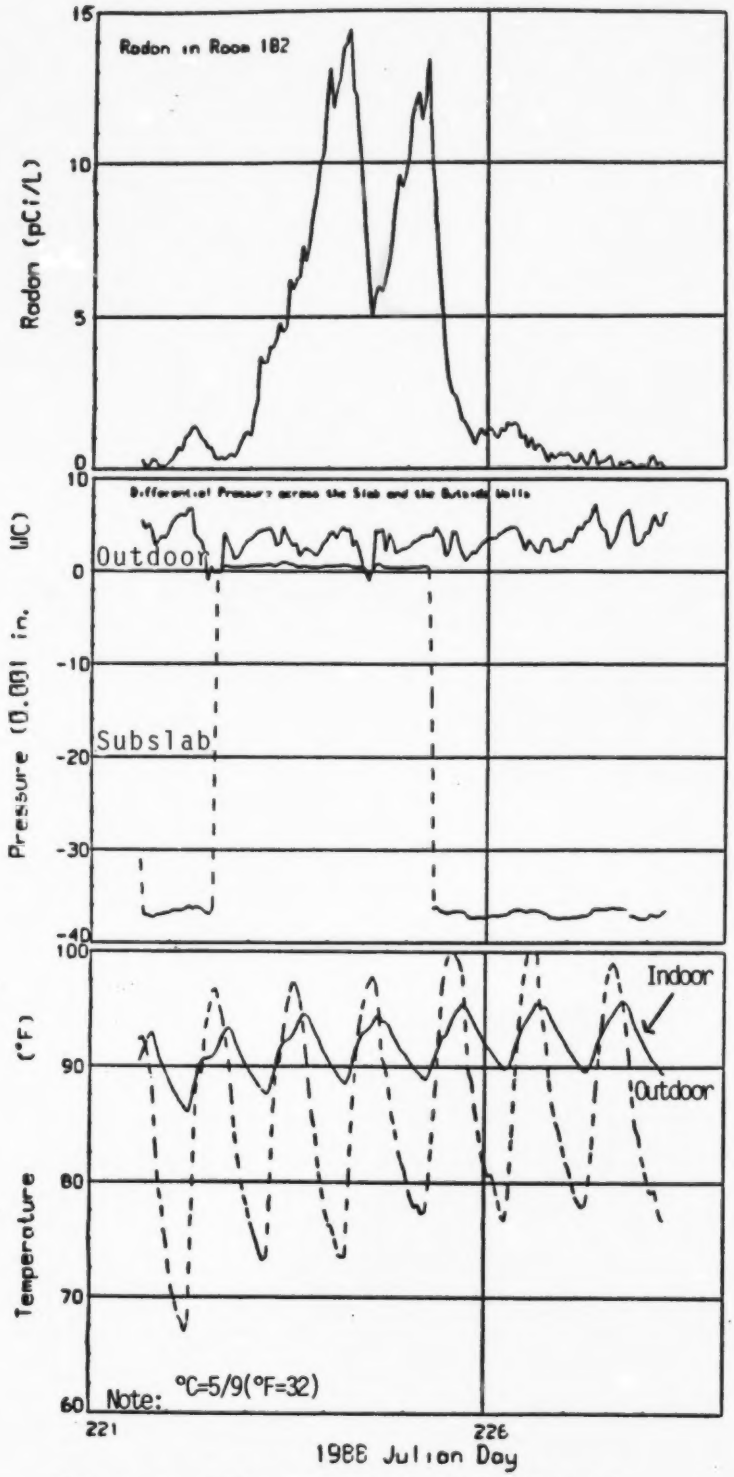


Figure 4. Effect of Single Point Subslab Depressurization on Radon Levels (Case Study D).

AEERL-P-588

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/D-89/206	2.
3. RECIPIENT'S ACCESSION NO.	
4. TITLE AND SUBTITLE Radon in Schools	5. REPORT DATE
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Kelly W. Leovic	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS See Block 12	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. NA (Inhouse)
12. SPONSORING AGENCY NAME AND ADDRESS **EPA, Office of Research and Development** Air and Energy Engineering Research Laboratory **Research Triangle Park, NC 27711**	13. TYPE OF REPORT AND PERIOD COVERED Published paper; 5/88 - 9/89
	14. SPONSORING AGENCY CODE **EPA/600/13**

15. SUPPLEMENTARY NOTES AEERL project officer is Kelly W. Leovic, Mail Drop 54, 919/541-7717. Presented at Indoor Air Quality Conference, Clearwater Beach, FL, 10/19-20/89.

16. ABSTRACT The paper discusses radon entry into schools, radon mitigation approaches for schools, and school characteristics (e.g., HVAC system design and operation) that influence radon entry and mitigation system design. It also discusses mitigation systems installed by the U.S. EPA in four schools. The primary source of radon entry into a school with significantly elevated radon levels is normally soil gas that is drawn in by pressure differentials between the soil surrounding the substructure and the building interior. If the building interior is at a lower pressure than the soil surrounding surrounding the substructure and radon is present in the soil, the radon can be pulled in through cracks and other openings that are in contact with the soil. The amount of radon in a given classroom depends on the level of radon in the underlying material, the ease with which the radon moves as a component of the soil gas through the soil, the magnitude and direction of the pressure differentials, the number and size of the radon entry routes, and dilution and mixing of the room air. HVAC systems in schools vary considerably and tend to have greater impact on pressure differentials--and consequently radon levels--than do heating and air-conditioning (HAC) systems in houses.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Soils Radon School Buildings Heating Ventilation Air Conditioning	Pollution Control Stationary Sources Soil Gas	13B 08G, 08M 07B 13M, 05I 13H, 13A

18. DISTRIBUTION STATEMENT **Release to Public**	19. SECURITY CLASS *(This Report)* **Unclassified**	21. NO. OF PAGES 23
	20. SECURITY CLASS *(This page)* **Unclassified**	22. PRICE

EPA Form 2220-1 (9-73)